## 3.0 THE EMF MIXTURE

A careful assessment of the electricity-related exposures from power lines, appliances, and occupations would reveal what amounts to a complex mixture with many aspects, such as EMFs with their respective frequency, polarization, etc. In this report these will be called the "aspects" of the mixture. Each aspect varies from instant to instant to form a time series of intensities that can be summarized as a single number by various summary "exposure metrics," which may be more or less biologically active. For example, the exposure metric of ionizing radiation that best predicts biological effects is the simple integral of the exposure time series. The exposure metric that best predicts the effect of an antibiotic might be the integral of blood levels above some threshold. Other electricity-related correlates of proximity to power lines, internal wiring, and appliances are not part of the fields at all, but might be correlated with them. These include contact currents from stray currents on plumbing and in the earth, and intermittent shocks. These will be called the "ingredients" of the mixture.

What aspects, ingredients, or exposure metrics, if any, should be considered in this risk evaluation?

EMFs associated with electric power are time-varying vectorial quantities. Since the fields alternate between symmetrical positive and negative values, their simple time average is zero. However, the energy associated with these fields is proportional to the ***square*** of their amplitude, therefore the field strength (often called ***intensity***) is expressed by the average of the square root of the square of the field (root mean square or ***rms***). The basic measure of human exposure to EMFs is the time-averaged rms of the intensity. In some studies, short-term measurements of the field taken in various environments were multiplied by a weight proportional to the time a subject spent in each of those environments and then averaged, hence the commonly used acronym TWA (time-weighted average) to indicate average rms of the field. A crude surrogate to assess exposure to average field is the so-called "wire coding," consisting of classifying residences based on their proximity to visible power lines and on the type of these power lines. For a number of years, some researchers believed that if the risk increase were truly due to some component of the EMF mixture that this component must be something other than the time-weighted average (something unintentionally captured by wire coding). Recent new data and reanalysis of old data (Linet et al., 1997), (Greenland et al., 2000) appear to have convincingly disposed of this hypothesis.

This does not mean that the other common metric used in epidemiological studies, the TWA measured by surrogates (e.g., point-in-time or "spot" measurements), calculations using engineering models and historical line current loads, and job exposure matrices) is necessarily the true causal agent. The units, mG or µT (1 µT = 10 mG), that measure the magnetic field's TWA do not describe the magnetic field (and much less the electric field associated with it) any more than the units marked on the volume dial on a stereo system describe the sound coming out of the speakers. Nevertheless, although the reviewers cannot definitely "rule in" the component(s) of interest, they can rule out some aspects of the fields which are not correlated with TWA field strength. Neutra and DelPizzo have a detailed discussion of this issue (Neutra & DelPizzo, 2001). Included here is a table adapted from that paper, pointing out which of the more commonly proposed metrics are indeed correlated to TWA and which are not (note that not all proposed metrics can be traced to the published literature, although they may have been discussed at professional meetings):

**TABLE 3.1.1**

| EXPOSURE METRIC TO 30-300 HZ MAGNETIC FIELDS | HIGH WIRE CODE | HIGH MEASURED FIELD | HEALTH ENDPOINT | REFERENCE |
|---|---|---|---|---|
| (1) TWA | U | U | U | many |
| (2) Length of time with constant field above a threshold | U | U | | |
| (3) Repeated periods of elevated exposure | U | U | U | (Feychting et al., 1997)<br>(Feychting et al., 1998b)<br>(Lee & McLoed, 1998) |
| (4) Third harmonic | U | ? | ? | (Kaune, 1994b) |
| (5) Resonance with static field | No | No | ? | (Kaune, 1994b)<br>(Bowman et al., 1995) |
| (6) Time above a threshold | U | U | ? | (von Winterfeldt & et. al., 2001) |
| (7) Polarization | ? | ? | ? | (Burch et al., 2000) |
| (8) Transients | No | No | ? | (Preece et al., 1999) |
| (9) Maximum daily exposure | U | U | U | (Li et al., 2002)<br>(Lee et al., 2002) |
| (10) Average change between measurements | U | U | U | (Lee et al., 2000) |
| (11) Electric field | Not inside home | Not inside home | ? | (Miller et al., 1996)<br>(Coghill et al., 1996) |

This table allows the reviewers at least to rule out two metrics that are supported by mechanistic arguments, but not (or at least not consistently) by empirical data: 1) magnetic field transient, which can induce strong, if brief, electrical currents in the body; and 2) resonance conditions, which may facilitate energy transfer from the field to the living organism.

The table also emphasizes the difficulty of testing the hypothesis of an EMF risk by conducting experimental studies. Studies using an exposure apparatus that delivers an appropriate TWA (but not an appropriate exposure to a hypothetical aspect, ingredient, or exposure metric found in residential or occupational environments) are liable to produce false-negative results. Alternatively, they may produce positive results which suggest dose-response relationships different from those that may result from environmental fields.

Reducing TWA exposure will reduce exposure to several other metrics and reduce any risk from TWA or the exposure metrics that are changed with it, although this is a sufficient, but not necessary condition. If TWA is not by itself the causal factor and if it could be identified and removed from the EMF mixture, the component directly causally associated with the health endpoint, a subject could still be exposed to strong average fields and not be at risk. Also, because the correlation between TWA and these other components of the field are modest to moderate, reducing TWA exposure, while reducing the risk, will not reduce it proportionally to the decrease in the average field strength.

The following table compares the values of the magnetic field strength (in mG) measured by direct personal measurement or by environmental monitoring (spot or 24-hour measurements).

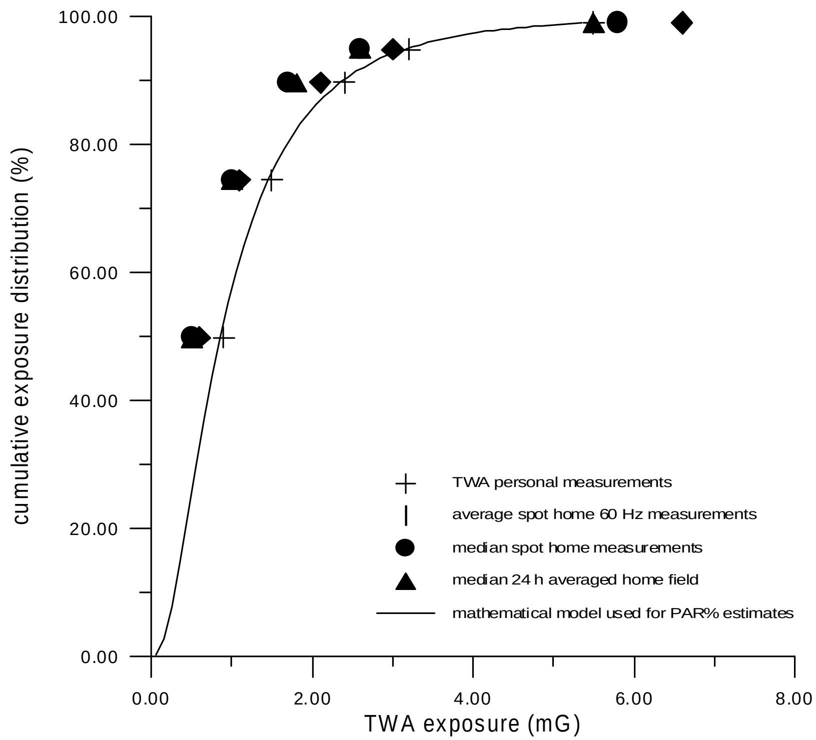
Note that these are not data collected on the same sample, but general information gleaned from the literature (Zaffanella, Savitz & Greenland, 1998), (Zaffanella, 1993), (Lee et al., 2000) and mathematical modeling.

**TABLE 3.1.2**

| PERCENTILE POINT | TWA PERSONAL FIELD | AVERAGE SPOT HOME MEASUREMENT (60 Hz) | MEDIAN SPOT HOME MEASUREMENT | MEDIAN 24- H HOME FIELD |
|---|---|---|---|---|
| 99 | 5.5 | 6.6 | 5.8 | 5.5 |
| 95 | 3.2 | 3 | 2.6 | 2.6 |
| 90 | 2.4 | 2.1 | 1.7 | 1.8 |
| 75 | 1.5 | 1.1 | 1 | 1 |
| 50 | 0.9 | 0.6 | 0.5 | 0.5 |

Figure 3.1.1 plots these data over a mathematical fit.

**Figure 3.1.1**




The personal TWA generally is higher than the environmental levels, reflecting the contribution that occasional close proximity to localized sources (appliances, wall wires, buried cables) makes to the average personal exposure. However, at the upper end of the distribution, this difference is minimal or non-existent, reflecting the fact that exposure to localized sources is common to all subjects averaging some tenths of an mG. What determines the "exposed" status of a subject in epidemiological studies (generally defined as a TWA above 2-4 mG) is usually the background environmental exposure and that is heavily contributed by home exposure (where people spend the most time). Certain occupations are an exception to this generalization because work-time exposure is so much higher than home exposure.

According to Zaffanella's "1000 homes study" (1995), these background fields are due, with almost equal frequency, to proximate power lines and to grounding system fields.

Of course, this conclusion will change drastically if future research confirms the hypothesis-generating data by Lee (2000) and Li (2000), indicating that, at least for spontaneous abortion (SAB), the true risk factor is the maximum daily exposure above 14 mG or the average field change between measurements. If maximum exposure is the appropriate metric, or one very strongly correlated to it, sources of localized fields (appliances, home wiring) become more important than power lines and ground currents because the latter seldom produce fields of the intensity implicated by the Lee and Li studies. An additional difficulty that will arise in this case is that personal measurements taken at the hip, as is common practice, may introduce errors that are large compared to the instrument error. This is because the field produced by a localized source often is very different when measured at different anatomical sites (DelPizzo, 1993) and because there is no clear evidence by which to determine if the EMFs interact with biological systems at specific target organs.

It must be stressed, however, that although these are recent, good-quality studies, they represent isolated findings which merit attention but do not negate the wealth of data associating average field to risk of other diseases.